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WOOD POLE MANAGEMENT BY NON-DESTRUCTIVE EVALUATION TECHNIQUES: BRITANNIA ROAD LINE - MILTON HYDRO

Report No. 90-150-K

S.G. Krishnasamy, A.A. Shehata
Applied Mechanics Section
Mechanical Research Department
and
B.W. Warkentin, Durham Instruments Ltd.
(formerly with Ontario Hydro)

ABSTRACT

A wood pole management program has been developed for upgrading a distribution line in Milton Hydro. The program utilizes the non-destructive evaluation technique developed by Electric Power Research Institute to establish the strength of each individual pole in the line. The strength data and the estimated wind and ice loads on each pole are used to draw a pole replacement/ reinforcement program for the line under investigation. The change in the reliability of the line due to the upgrading is calculated. A study is done to evaluate the economic benefits of using the proposed pole management program.

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EXECUTIVE SUMMARY

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Applied Mechanics Section
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and
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The strength of wood poles degrades with time. Thus to maintain the safety and security of power lines, sound engineering decisions have to be made to manage life and maintenance programs for wood poles. One of the essential elements in managing wood pole lines is to assess the strength of in-service poles. The traditional pole testing methods, such as the boring technique, are based more on personal judgement and experience rather than on consistent testing procedures. Hence the decisions based on the traditional methods may be less consistent and accurate than those based on some of the modern non-destructive evaluation (NDE) techniques. One such an NDE technique, developed by Electric Power Research Institute, is used in the present study to develop a maintenance program for a wood pole distribution line in Milton Hydro.

This report describes a 5-year maintenance program for the Britannia Road distribution line in Milton Hydro. The NDE equipment is utilized to establish the strength of each individual pole in the line. The strength data and the wind and ice loads obtained from climatic data are then used to evaluate the adequacy of each pole and to make decisions on pole management.

The implementation of the suggested maintenance program will result in considerable savings to Milton Hydro. In fact, Milton Hydro has accepted the recommendations of this study and embarked on a cooperative effort with Ontario Hydro to develop a maintenance program for approximately 7,000 additional poles in its power grid.

JC
BC

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1. Currently with Durham Instruments Ltd., formerly with Ontario Hydro.

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To Mr. D. Thorne
Manager, Milton Hydro
Milton, Ontario

WOOD POLE MANAGEMENT BY NON-DESTRUCTIVE EVALUATION TECHNIQUES: BRITANNIA ROAD LINE - MILTON HYDRO

1.0 INTRODUCTION

In the spring of 1988, a rural power distribution line along Britannia Road in Milton, Ontario (Figures 1-2) lost several wood poles as a result of a wind storm in that area. The 27.6 kV, approximately 11 km long, line has been in service for more than 40 years and is an important segment of the Milton Hydro electrical distribution power grid. It has been assessed that approximately 30 percent of the poles in the line segment are 40 years of age or older.

A preliminary review by the Milton Hydro engineers resulted in the following information about the existing line:

- A number of poles were mechanically damaged, weakened by ground line decay and insect damage (Figures 3-6).
- The apparent poor physical condition of the line may significantly reduce its overall reliability to deliver uninterrupted power to consumers.
- Britannia Road has been designated by the Regional Municipality for possible widening in two stages:

  a) a certain portion of the road will be widened in 1989
  b) the remaining will possibly be widened in 1994[1].

The apparent poor condition of the line and the uncertainty regarding the widening of Britannia Road have led Milton Hydro to consider all the possible options available before taking any decision to repair the existing line. Ontario Hydro, at the request of Milton Hydro, has agreed to a cooperative effort to assess the condition of the line and devise ways to improve the reliability of the line. The following options were considered:

---

1. While planning for the 1989 widening is complete, the plans for the 1994 widening are still under consideration.

Option No. 1

- Replace the entire line in 1989 but relocate only that portion of it along the road designated for widening in 1989.
- Relocate the remaining line in 1994.

Option No. 2

- Replace and relocate now only that portion of the line along the road designated for widening in 1989.
- Upgrade the remaining in 1989, replacing and reinforcing only a selected number of poles, and then relocate it in 1994.

Option No. 1 does not require any evaluation of poles because all the existing poles will be replaced by new ones. However, if Option No. 2 is adopted then the poles in the line along the road designated for widening should be evaluated before any upgrading work is done.

The pole evaluation could be done primarily in two ways:

- Use conventional boring technique to assess the remaining pole strength.

- Apply the modern non-destructive evaluation (NDE) technique to estimate pole strength.

The modern NDE technique, which is considered to be more accurate and consistent than the conventional method, has been chosen for this project. The non-destructive evaluation equipment (POLETEST™) originally developed by Electric Power Research Institute (EPRI) and marketed by Engineering Data Management (EDM), was used in this study.

The POLETEST™ was used to estimate the strength of each individual pole in the Britannia Road line. Along with pole strength data, information was also gathered on pole height, span length and structural damage to the poles. The load on each individual pole due to wind and ice was estimated using the data from the Toronto (Lester B. Pearson) International Airport weather station. Both the pole strength data and the weather related load information were used to make the following decisions or estimates:

- Decide on the poles that need replacement or reinforcement.

- Estimate the reliability of the line before and after upgrading.

- Carry out a cost/benefit analysis to choose the most economical of the two options described above.

It should be pointed out that the condition of a pole below ground line should be evaluated using other available techniques since the NDE technique used in this study is not designed to detect decay below ground line.

2.0 DETAILS OF THE BRITANNIA ROAD LINE

The line section under study has about 260 wood pole structures. Of the 260 poles, about 90% are cedar and the rest are pine. The poles had an average height of approximately 12 m and some of these support telephone cable, transformers, switch assemblies and street lamps. Some of the poles in the line are over 40 years old while others have only been in service for a few years. Some typical details on pole height, span length, conductor sizes, etc., are given in Table 1.

3.0 DESCRIPTION OF THE NON-DESTRUCTIVE EVALUATION (NDE) TECHNIQUE

The EDM non-destructive evaluation technique applies the principles of ultrasonic sound (stress wave induced vibration) to create a sound/stress signal in the material /1/. The received ultrasonic test signal is analyzed and compared to a machine-stored data base relating the ultrasonic signal and pole strength. The ultrasonic signal varies depending on the type of pole species, the degree of material degradation as well as other parameters that affect the material properties. By comparing the received signal to that of the stored data base for that pole species, a measure of the pole strength is determined. The procedure for applying the NDE equipment to estimate individual pole strength is described in /1/. The equipment is data dependent and uses a data base established by EDM.

The data base was established by first testing the pole using non-destructive technique and then breaking it in cantilever bending to provide actual strength data. Data are currently available for Douglas-fir, Southern Pine and Western Red Cedar species. At present, information for over one thousand poles are incorporated into the data base.

4.0 ESTIMATION OF INDIVIDUAL POLE STRENGTH - BRITANNIA ROAD LINE

Each pole was tested using the POLETEST™ equipment and its strength was determined. This value was subsequently reduced by 600 psi, which is the standard error of estimate associated with the predicted strength of a pole using the equipment, as suggested by the manufacturer/1/. The estimated strength of each individual pole is listed in Table 2. Since 20 of the 260 poles tested were found to have negligible strength they were not included in the subsequent analysis. The mean strength, standard deviation and coefficient of variation (COV) of the 240 poles are 25.46 MPa, 8.77 MPa and 34% respectively (Table 3). The pole strength distribution is shown in the form of a histogram in Figure 7 and the estimated pole strength values are used later in the pole management decision.

5.0 WEATHER RELATED LOADS ON POLES

According to the Canadian Standard Association (CSA) specifications, overhead distribution lines should be designed to withstand a wind load of 383 Pa (8 psf) superimposed on a 12.7 mm (1/2 inch) radial ice on the conductor. The CSA design load (usually specified as "1/2 inch + 8 psf") is used across Canada and does not explicitly recognize the variation due to different terrain and topological conditions. Hence it was decided in this study to use the more realistic wind and ice loads derived from historical weather data gathered at the nearby Toronto International Airport instead of the CSA design load.

5.1 Conductor Loads from Weather Data

Wind, ice and wind-on-ice load values for the two conductor sizes were calculated using the weather data from the Toronto International Airport/2/. The values used in the analysis correspond to the upper 95% confidence limit with 50 year return period (see Figure 8) of the mean annual extreme loads.

Only transverse loads acting on the conductors (i.e., wind and wind-on-ice loads) are considered in the analysis and the vertical loads due to ice, transformers and pole weight are neglected. Typical values of loads due to wind, ice and wind-on-ice are listed in Table 4. In calculating the transverse loads, the two-second gust wind values are used in accordance with Ontario Hydro practice. Since the gust wind-on-ice load was larger than the wind load, the former was used in the analysis.

5.2 Maximum Stress in the Pole Due to Transverse Wind-on-Ice Loads

To calculate the maximum fibre stress due to the wind-on-ice loads, the following procedure was followed:

- Determine the pole height and the effective conductor attachment level from the ground line.
- Determine the effective span length to calculate the total load on the pole.
- Calculate the maximum ground line bending stress in the pole due to the applied wind-on-ice loads.
- Repeat above steps for each pole tested.

The maximum fibre stress on each pole is shown in Table 2.

5.3 Estimation of Pole Strength Degradation

About 92 of all the cedar poles tested were found to be 40 years of age or older. Of these 92 poles, 15 were found to have negligible strength. The mean fibre strength, standard deviation and coefficient of variation (COV) of the remaining 77 poles are 18.75 MPa, 9.48 MPa and 51% respectively (Table 3). Assuming that the mean strength of Western Red Cedar is 41.37 MPa (6000 psi), the degradation rate over 40 years is estimated to be 0.565 MPa/yr. This strength degradation of poles has been used in estimating the strength of poles for the next five years (Table 2).

6.0 GUIDELINES FOR POLE MANAGEMENT

Management of aged poles can be done in two ways:

a) All the poles with strength below a certain predetermined value (irrespective of the load on them) should be replaced.

b) Only those poles with strength below the maximum bending stress due to the transverse wind-on-ice load on them would be replaced.

If criterion a) is applied in the pole management, it is possible that poles with considerably more strength than required to support the loads on them would be removed. Therefore, it would be much more realistic to use criterion b) by which pole management is based upon the actual load that a pole must support.

The procedure for pole management based on criterion b) is illustrated in Figure 9 and described below in detail.

STEP 1) Determine the difference (ΔS) between the pole strength and maximum fibre stress due to the applied load.

STEP 2) If the difference (ΔS) is positive (pole strength is greater than the stress due to the load on it) then follow either step (2a) or (2b):

a) If pole strength is greater than 50% of new mean pole strength (41.37 MPa) then no need for any action.

b) If pole strength is less than 50% of new mean pole strength then apply either step b1) or b2):

b1) If pole strength is less than twice the maximum fibre stress due to the applied load then replace the pole.

b2) If the pole strength is greater than or equal to twice the maximum fibre stress due to the applied load then reinforce the pole by guying or other means.

STEP 3) If the difference (ΔS) is negative then follow either step (3a) or (3b):

a) If pole strength is less than 50% of the new pole mean strength then replace the pole.

b) If pole strength is greater than 50% of the new mean pole strength then follow either step b1) or b2):

b1) If the difference (ΔS) is greater than 5% of the new mean pole strength then replace the pole.

b2) If the difference (ΔS) is less than or equal to 5% of the new mean pole strength then reinforce the pole by guying or other means.

STEP 4) Repeat the above steps for each pole tested.

This procedure provides a systematic approach for pole management and thus reduces the possibility of premature pole removal. A computer program has been written to automate the above process. Applying the strength degradation rate calculated earlier the computer program has been used to estimate the number of poles that have to be removed/reinforced in the next 5 years (Table 5).

The strength of each new or reinforced pole is assumed to be 41.37 MPa. The estimated mean strength, standard deviation and COV of the 260 poles in the upgraded line are 32.28 MPa, 7.32 MPa and 23% respectively. The increase in the mean strength of poles after replacement/reinforcement is about 27%. The variation of pole strength after replacement/reinforcement is shown in the form of a histogram in Figure 10.

7.0 RELIABILITY OF BRITANNIA ROAD LINE

Even though initially the non-destructive evaluation was carried out on an 11.2 km long section of the line, Milton Hydro finally decided to upgrade only an 8 km sector consisting of 220 poles. Hence, the reliability calculations are done based on the information for the 220 poles.

The result of the pole management procedure described above is to increase the line reliability after the weak poles are replaced or reinforced as recommended in Table 5. The relative reliability of the upgraded line with respect to the old one will be calculated using the load distribution on the line and the distributions of the pole strength before and after upgrading.

The procedure for reliability calculations is outlined below:

- The maximum fibre stress due to wind-on-ice load on each pole is assumed to be an extreme value distribution.
- The pole strength distributions before and after upgrading are assumed to be normal.
- The reliability of the line before and after upgrading is calculated.
- The relative increased reliability of the upgraded line which is equal to (reliability of the upgraded line/reliability of the old line) is calculated.

It should be pointed out that the main objective is to calculate the relative increase in reliability rather than the absolute reliability of the line before and after upgrading. The relative reliability increase shows that the line's overall ability to support the weather-related loads has increased approximately by a factor of 3.

8.0 COST-BENEFIT ANALYSIS

A cost-benefit analysis was carried out to estimate the overall savings that Milton Hydro would realize in upgrading the 8 km section of the existing Britannia Road line. Property acquisitions for relocating the first 3.2 km section of the line have been completed and the relocating work could be completed in 1989. However, the preparatory work for the remaining 4.8 km length will not be completed before the end of 1990. Two possible scenarios (or options) discussed in the introduction were considered in the cost-benefit analysis:

Option #1

- Replace the entire 8 km line in 1989 but relocate only the 3.2 km length in 1989.
- Relocate the remaining 4.8 km length in 1994.

Option #2

- Replace and relocate the 3.2 km length in 1989.
- Upgrade the remaining 4.8 km length in 1989, replacing and reinforcing only a selected number of poles, and relocate it in 1994.

The cost of these two options will be estimated separately and then compared to choose the most beneficial one for implementation.

The following assumptions are made in the cost-benefit analysis (all costs are in 1989 dollars):

- Total cost for new line = $70,000/km (labour portion of the cost = $31,200/km).
- Transfers and removals (old line) = $17,500/km.
- Cost for individual pole replacement = $2,600/pole.
- Guying of poles: without-stub pole = $500/pole, with-stub pole = $1,000/pole.

Cost Estimate for Option No. 1

Cost to replace the entire 8 km line and relocate the 3.2 km in 1989:	$ 700,000 *
Cost to relocate the 4.8 km length in 1994:	$ 336,000 **
Total cost:	$1,036,000

* Cost per km = $87,500 ($70,000 + $17,500)
** Cost per km = $70,000

Cost Estimate for Option No. 2

Replace and relocate 3.2 km line in 1989:	$280,000
Replace or reinforce 31 poles in the remaining 4.8 km line:	$ 80,600
Replace and relocate 4.8 km in 1994:	$470,000
Total cost:	$780,600

Cost Benefit Comparison

Cost for Option No. 1:	$1,036,000
Cost for Option No. 2:	$ 780,600
Net Savings if Option No. 2 is chosen:	$ 255,400

Since the savings is at least $250,000 if Option No. 2 is chosen, Milton Hydro has officially accepted it for implementation.

9.0 SUMMARY AND CONCLUSIONS

Milton Hydro has, in general, two options available to it with respect to a 8.2 km segment of a distribution line built more than 40 years ago:

- replace the entire line immediately, or
- replace only those poles that are not strong enough to withstand the loads on them.

Since the traditional pole testing methods, such as the boring technique, may not be reliable, a non-destructive technique has been used to estimate the strength of poles in a 8.2 km stretch of the line along Britannia Road in Milton. By comparing the strength of each individual pole with that of the load on it, a pole management criteria has been established to identify poles that need to be replaced or strengthened.

The load and strength data have been used to study the following:

- The change in the reliability of the line as a result of replacing or reinforcing the weak poles.
- The economic benefits of upgrading the line only by replacing/strengthening the weak poles only, instead of replacing the whole line.

The cost-benefit study indicates that at least $250,000 can be saved by upgrading the existing line instead of entirely replacing it. The reliability of the upgraded line will be three times that of the existing line.

Based on the results of this study and also considering the plans for future road widening in that region, Milton Hydro decided on the following plan of action:

- In 1989, relocate 3.2 km section of the line and upgrade the remaining 4.8 km stretch
- In 1994, if the road widening plans are complete, relocate the remaining 4.8 km section of the line.

It may be noted here that the pole management program proposed in this report has been developed on the basis of certain guidelines as detailed in Section 6. These guidelines are derived from the author's experience as well as the utility industry practices in this field. However, those guidelines can be made more stringent or lenient according to the required reliability level of the line under consideration.

10.0 RELATED WORK

Milton Hydro has embarked on a cooperative effort with Ontario Hydro to apply the NDE technique to assess the strength of approximately 7,000 wood poles in its power grid to establish a data base for use in line maintenance and operation.

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Reviewed by:

J. A. Chadha
Supervising Engineer
Applied Mechanics Section

Submitted:

S.G. Krishnasamy
Unit Head-Transmission, Distribution & Structures
Applied Mechanics Section

Approved by:

G.J. Clarke
Manager
Mechanical Research Department

A.A. Shehata
Engineer
Applied Mechanics Section

SGK/AAS:cr

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1. EDM - Engineering Data Management Inc., Model PT 101 Technical Supplement, Version 1.11, Techware Division, Fort Collins, Colorado 80525, 1987.

2. Krishnasamy, S.G. and M. Tabatabai, "Data Base for Weather Related Loads on Overhead Transmission Lines in Ontario", Ontario Hydro Research Division Report No. 88-220-K, Toronto, 1988.

TABLE 1

INFORMATION ON THE BRITANNIA ROAD LINE

Average Pole Height (m)	Range of Pole Height (m)	Average Span Length (m)	Range of Span Length (m)	Number of Conductors	Conductor Sizes (mm)	Type of Terrain
12	10–18	43	3–73	6	12.0	Flat Rural Farmland
				1	9.5	Some Residential Housing

TABLE 2

MAXIMUM STRESS AND POLE STRENGTH FORECAST OVER 5 YEAR PERIOD

POLE I.D. NO.	MAX. STRESS (MPa)	POLE STRENGTH (MPa)				
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
1	13.48	29.30	28.74	28.17	27.61	27.04
2	16.45	26.27	25.70	25.14	24.57	24.01
3	17.74	25.17	24.60	24.04	23.47	22.91
4	27.62	27.92	27.36	26.79	26.23	25.66
5	15.02	24.13	23.57	23.00	22.44	21.87
6	25.13	26.34	25.77	25.21	24.64	24.08
7	15.76	26.55	25.98	25.41	24.85	24.28
8	32.28	39.99	39.43	38.86	38.29	37.73
9	15.09	25.30	24.74	24.17	23.61	23.04
10	15.79	14.00	13.43	12.87	12.30	11.74
11	19.66	25.17	24.60	24.04	23.47	22.91
12	13.18	30.34	29.77	29.21	28.64	28.08
13	18.38	13.72	13.16	12.59	12.02	11.46
14	19.14	25.17	24.60	24.04	23.47	22.91
15	25.26	26.55	25.98	25.41	24.85	24.28
16	25.64	25.44	24.88	24.31	23.75	23.18
17	27.29	40.40	39.84	39.27	38.71	38.14
18	17.05	0.00	0.00	0.00	0.00	0.00
19	14.96	28.68	28.12	27.55	26.99	26.42
20	24.57	39.99	39.43	38.86	38.29	37.73
21	11.59	25.30	24.74	24.17	23.61	23.04
22	10.23	23.03	22.46	21.90	21.33	20.77
23	26.26	45.09	44.53	43.96	43.40	42.83
24	19.70	24.68	24.12	23.55	22.99	22.42
25	30.44	38.89	38.32	37.76	37.19	36.63
26	16.93	25.79	25.22	24.66	24.09	23.53
27	13.07	24.20	23.64	23.07	22.51	21.94
28	9.10	26.20	25.64	25.07	24.50	23.94
29	8.61	0.00	0.00	0.00	0.00	0.00
30	5.23	15.93	15.36	14.80	14.23	13.67
31	9.42	1.45	0.88	0.32	0.00	0.00
32	12.51	40.20	39.63	39.07	38.50	37.94
33	4.99	0.00	0.00	0.00	0.00	0.00
34	12.78	36.54	35.98	35.41	34.85	34.28
35	13.91	26.20	25.64	25.07	24.50	23.94
36	14.94	27.37	26.81	26.24	25.68	25.11
37	5.17	0.00	0.00	0.00	0.00	0.00
38	12.39	29.17	28.60	28.04	27.47	26.90
39	7.55	0.00	0.00	0.00	0.00	0.00
40	24.11	40.13	39.56	39.00	38.43	37.87
41	8.85	30.41	29.84	29.28	28.71	28.15

TABLE 2 cont'd

POLE I.D. NO.	MAX. STRESS (MPa)	POLE STRENGTH (MPa)				
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
42	7.45	5.03	4.47	3.90	3.34	2.77
43	4.83	0.00	0.00	0.00	0.00	0.00
44	15.53	39.09	38.53	37.96	37.40	36.83
45	10.88	26.61	26.05	25.48	24.92	24.35
46	12.65	25.93	25.36	24.79	24.23	23.66
47	8.28	23.72	23.15	22.59	22.02	21.46
48	6.32	25.58	25.02	24.45	23.88	23.32
49	9.47	27.65	27.08	26.52	25.95	25.39
50	6.90	27.03	26.46	25.90	25.33	24.77
51	8.43	26.55	25.98	25.41	24.85	24.28
52	11.25	23.93	23.36	22.79	22.23	21.66
53	9.81	12.55	11.98	11.42	10.85	10.29
54	18.38	24.34	23.77	23.21	22.64	22.08
55	16.95	25.65	25.08	24.52	23.95	23.39
56	27.34	25.03	24.46	23.90	23.33	22.77
57	26.46	23.79	23.22	22.66	22.09	21.53
58	19.25	39.99	39.43	38.86	38.29	37.73
59	23.49	23.99	23.43	22.86	22.30	21.73
60	32.35	24.55	23.98	23.42	22.85	22.28
61	9.82	26.48	25.91	25.35	24.78	24.22
62	20.26	26.34	25.77	25.21	24.64	24.08
63	30.65	40.89	40.32	39.76	39.19	38.63
64	21.80	24.75	24.19	23.62	23.06	22.49
65	20.33	24.34	23.77	23.21	22.64	22.08
66	4.89	19.65	19.09	18.52	17.95	17.39
67	10.94	9.58	9.02	8.45	7.89	7.32
68	13.27	24.75	24.19	23.62	23.06	22.49
69	17.40	0.00	0.00	0.00	0.00	0.00
70	9.54	0.00	0.00	0.00	0.00	0.00
71	6.87	3.31	2.74	2.18	1.61	1.05
72	22.49	26.20	25.64	25.07	24.50	23.94
73	20.23	26.89	26.33	25.76	25.19	24.63
74	24.84	24.96	24.39	23.83	23.26	22.70
75	27.38	14.48	13.91	13.35	12.78	12.22
76	10.19	0.00	0.00	0.00	0.00	0.00
77	15.12	38.96	38.39	37.83	37.26	36.70
78	22.21	47.16	46.60	46.03	45.47	44.90
79	22.83	26.82	26.26	25.69	25.13	24.56
80	24.97	25.30	24.74	24.17	23.61	23.04
81	12.37	29.72	29.15	28.59	28.02	27.46
82	7.96	27.37	26.81	26.24	25.68	25.11
83	10.60	6.27	5.71	5.14	4.58	4.01
84	12.82	25.79	25.22	24.66	24.09	23.53

TABLE 2 cont'd

POLE I.D. NO.	MAX. STRESS (MPa)	POLE STRENGTH (MPa)				
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
85	8.61	25.72	25.15	24.59	24.02	23.46
86	10.57	23.99	23.43	22.86	22.30	21.73
87	9.00	25.24	24.67	24.10	23.54	22.97
88	8.64	28.89	28.32	27.76	27.19	26.63
89	9.22	24.82	24.26	23.69	23.13	22.56
90	25.37	24.89	24.33	23.76	23.19	22.63
91	8.33	26.89	26.33	25.76	25.19	24.63
92	23.75	29.86	29.29	28.72	28.16	27.59
93	15.63	28.82	28.26	27.69	27.12	26.56
94	9.87	0.00	0.00	0.00	0.00	0.00
95	15.86	11.10	10.54	9.97	9.40	8.84
96	10.71	15.93	15.36	14.80	14.23	13.67
97	12.65	27.86	27.29	26.73	26.16	25.59
98	8.38	4.14	3.57	3.01	2.44	1.88
99	12.34	25.65	25.08	24.52	23.95	23.39
100	6.34	0.00	0.00	0.00	0.00	0.00
101	15.20	25.65	25.08	24.52	23.95	23.39
102	16.44	25.51	24.95	24.38	23.82	23.25
103	13.68	28.48	27.91	27.35	26.78	26.21
104	10.58	3.79	3.23	2.66	2.10	1.53
105	28.35	41.71	41.15	40.58	40.02	39.45
106	10.44	30.68	30.12	29.55	28.99	28.42
107	14.25	26.68	26.12	25.55	24.99	24.42
108	18.93	26.89	26.33	25.76	25.19	24.63
109	14.64	31.51	30.94	30.38	29.81	29.25
110	19.84	7.93	7.36	6.80	6.23	5.67
111	15.74	0.00	0.00	0.00	0.00	0.00
112	21.75	26.55	25.98	25.41	24.85	24.28
113	10.27	26.96	26.39	25.83	25.26	24.70
114	17.29	28.20	27.64	27.07	26.50	25.94
115	10.09	18.75	18.19	17.62	17.06	16.49
116	14.84	25.10	24.53	23.97	23.40	22.84
117	9.38	0.00	0.00	0.00	0.00	0.00
118	10.41	24.82	24.26	23.69	23.13	22.56
119	21.22	29.65	29.08	28.52	27.95	27.39
120	17.65	44.89	44.32	43.76	43.19	42.62
121	9.94	9.17	8.60	8.04	7.47	6.91
122	20.71	24.82	24.26	23.69	23.13	22.56
123	13.92	26.82	26.26	25.69	25.13	24.56
124	10.87	24.68	24.12	23.55	22.99	22.42
125	7.79	28.34	27.77	27.21	26.64	26.08
126	25.37	24.82	24.26	23.69	23.13	22.56
127	13.58	22.27	21.71	21.14	20.57	20.01
128	8.83	24.75	24.19	23.62	23.06	22.49

TABLE 2 cont'd

POLE I.D. NO.	MAX. STRESS (MPa)	POLE STRENGTH (MPa)				
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
129	7.30	0.00	0.00	0.00	0.00	0.00
130	8.87	5.10	4.54	3.97	3.41	2.84
131	22.84	47.23	46.67	46.10	45.53	44.97
132	12.95	40.06	39.49	38.93	38.36	37.80
133	13.27	11.24	10.67	10.11	9.54	8.98
134	14.15	37.16	36.60	36.03	35.47	34.90
135	22.45	27.65	27.08	26.52	25.95	25.39
136	10.94	28.96	28.39	27.83	27.26	26.70
137	21.28	28.61	28.05	27.48	26.92	26.35
138	16.18	26.75	26.19	25.62	25.06	24.49
139	14.42	25.03	24.46	23.90	23.33	22.77
140	20.29	29.86	29.29	28.72	28.16	27.59
141	25.25	24.82	24.26	23.69	23.13	22.56
142	12.53	9.93	9.36	8.80	8.23	7.67
143	27.15	24.68	24.12	23.55	22.99	22.42
144	21.06	27.86	27.29	26.73	26.16	25.59
145	9.39	27.37	26.81	26.24	25.68	25.11
146	11.60	26.20	25.64	25.07	24.50	23.94
147	12.17	0.00	0.00	0.00	0.00	0.00
148	14.38	29.30	28.74	28.17	27.61	27.04
149	22.74	25.86	25.29	24.73	24.16	23.59
150	24.64	43.30	42.74	42.17	41.60	41.04
151	11.01	10.34	9.78	9.21	8.65	8.08
152	8.00	27.44	26.88	26.31	25.75	25.18
153	22.26	27.30	26.74	26.17	25.61	25.04
154	8.38	27.65	27.08	26.52	25.95	25.39
155	16.22	25.44	24.88	24.31	23.75	23.18
156	20.11	31.79	31.22	30.66	30.09	29.52
157	17.47	27.58	27.01	26.45	25.88	25.32
158	20.94	26.55	25.98	25.41	24.85	24.28
159	25.24	25.24	24.67	24.10	23.54	22.97
160	34.93	37.92	37.36	36.79	36.23	35.66
161	26.08	25.93	25.36	24.79	24.23	23.66
162	12.34	25.79	25.22	24.66	24.09	23.53
163	9.94	14.34	13.78	13.21	12.65	12.08
164	21.31	25.51	24.95	24.38	23.82	23.25
165	27.84	26.55	25.98	25.41	24.85	24.28
166	21.96	3.45	2.88	2.32	1.75	1.19
167	16.19	1.65	1.09	0.52	0.00	0.00
168	20.73	28.82	28.26	27.69	27.12	26.56
169	5.82	26.41	25.84	25.28	24.71	24.15
170	4.96	7.17	6.61	6.04	5.47	4.91
171	9.47	3.24	2.68	2.11	1.54	0.98
172	23.17	27.58	27.01	26.45	25.88	25.32

TABLE 2 cont'd

POLE I.D. NO.	MAX. STRESS (MPa)	POLE STRENGTH (MPa)				
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
173	27.21	30.41	29.84	29.28	28.71	28.15
174	41.90	40.13	39.56	39.00	38.43	37.87
175	28.59	25.10	24.53	23.97	23.40	22.84
176	28.29	26.48	25.91	25.35	24.78	24.22
177	10.73	26.55	25.98	25.41	24.85	24.28
178	1.82	34.61	34.05	33.48	32.92	32.35
179	3.27	25.86	25.29	24.73	24.16	23.59
180	8.45	24.96	24.39	23.83	23.26	22.70
181	12.93	27.92	27.36	26.79	26.23	25.66
182	9.55	31.23	30.67	30.10	29.54	28.97
183	13.42	26.13	25.57	25.00	24.44	23.87
184	21.31	26.89	26.33	25.76	25.19	24.63
185	22.97	25.03	24.46	23.90	23.33	22.77
186	10.24	13.17	12.60	12.04	11.47	10.91
187	9.37	0.97	0.40	0.00	0.00	0.00
188	24.49	24.55	23.98	23.42	22.85	22.28
189	16.03	7.45	6.88	6.32	5.75	5.19
190	18.95	26.89	26.33	25.76	25.19	24.63
191	14.62	25.30	24.74	24.17	23.61	23.04
192	25.04	25.44	24.88	24.31	23.75	23.18
193	22.45	26.06	25.50	24.93	24.37	23.80
194	22.34	27.86	27.29	26.73	26.16	25.59
195	16.06	26.75	26.19	25.62	25.06	24.49
196	9.27	0.00	0.00	0.00	0.00	0.00
197	15.07	26.27	25.70	25.14	24.57	24.01
198	17.20	25.51	24.95	24.38	23.82	23.25
199	18.40	0.00	0.00	0.00	0.00	0.00
200	20.11	26.75	26.19	25.62	25.06	24.49
201	16.16	1.72	1.16	0.59	0.03	0.00
202	23.37	30.48	29.91	29.35	28.78	28.21
203	17.47	10.48	9.92	9.35	8.78	8.22
204	20.65	24.20	23.64	23.07	22.51	21.94
205	20.70	24.89	24.33	23.76	23.19	22.63
206	9.36	16.20	15.64	15.07	14.51	13.94
207	23.42	24.62	24.05	23.48	22.92	22.35
208	8.88	25.86	25.29	24.73	24.16	23.59
209	9.62	29.37	28.81	28.24	27.68	27.11
210	14.69	25.72	25.15	24.59	24.02	23.46
211	15.80	27.30	26.74	26.17	25.61	25.04
212	26.06	31.30	30.74	30.17	29.61	29.04
213	15.84	24.48	23.91	23.35	22.78	22.22
214	21.96	25.93	25.36	24.79	24.23	23.66
215	18.95	2.90	2.33	1.77	1.20	0.63
216	10.04	27.24	26.67	26.10	25.54	24.97

TABLE 2 cont'd

POLE I.D. NO.	MAX. STRESS (MPa)	POLE STRENGTH (MPa)				
		YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
217	19.43	40.06	39.49	38.93	38.36	37.80
218	8.20	27.37	26.81	26.24	25.68	25.11
219	19.88	26.75	26.19	25.62	25.06	24.49
220	15.47	40.13	39.56	39.00	38.43	37.87
221	19.69	38.89	38.32	37.76	37.19	36.63
222	20.88	25.03	24.46	23.90	23.33	22.77
223	8.56	9.58	9.02	8.45	7.89	7.32
224	9.24	22.62	22.05	21.48	20.92	20.35
225	23.81	39.99	39.43	38.86	38.29	37.73
226	8.91	19.44	18.88	18.31	17.75	17.18
227	14.27	25.10	24.53	23.97	23.40	22.84
228	17.11	25.30	24.74	24.17	23.61	23.04
229	26.65	24.41	23.84	23.28	22.71	22.15
230	9.98	24.41	23.84	23.28	22.71	22.15
231	6.74	23.93	23.36	22.79	22.23	21.66
232	19.25	16.34	15.78	15.21	14.64	14.08
233	5.83	20.75	20.19	19.62	19.06	18.49
234	24.24	25.99	25.43	24.86	24.30	23.73
235	5.10	23.24	22.67	22.11	21.54	20.97
236	13.45	26.68	26.12	25.55	24.99	24.42
237	11.67	25.65	25.08	24.52	23.95	23.39
238	9.93	28.34	27.77	27.21	26.64	26.08
239	6.53	24.62	24.05	23.48	22.92	22.35
240	9.72	25.93	25.36	24.79	24.23	23.66
241	13.96	34.41	33.84	33.28	32.71	32.14
242	11.12	29.65	29.08	28.52	27.95	27.39
243	15.80	0.00	0.00	0.00	0.00	0.00
244	32.20	6.07	5.50	4.94	4.37	3.81
245	11.32	30.68	30.12	29.55	28.99	28.42
246	21.16	25.86	25.29	24.73	24.16	23.59
247	13.16	25.24	24.67	24.10	23.54	22.97
248	13.69	26.48	25.91	25.35	24.78	24.22
249	12.18	34.20	33.63	33.07	32.50	31.94
250	22.20	40.06	39.49	38.93	38.36	37.80
251	7.90	26.55	25.98	25.41	24.85	24.28
252	13.62	25.17	24.60	24.04	23.47	22.91
253	11.97	28.68	28.12	27.55	26.99	26.42
254	24.47	30.61	30.05	29.48	28.92	28.35
255	31.46	23.79	23.22	22.66	22.09	21.53
256	34.68	40.61	40.05	39.48	38.92	38.35
257	30.72	29.79	29.22	28.66	28.09	27.52
258	7.57	0.00	0.00	0.00	0.00	0.00
259	13.29	29.17	28.60	28.04	27.47	26.90
260	10.71	0.00	0.00	0.00	0.00	0.00

TABLE 3

STATISTICAL PARAMETERS OF POLE STRENGTH BEFORE LINE UPGRADING

Statistical Parameter	Mean Strength (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)	No. of Poles Tested	No. of Poles with Negligible Strength
Poles (no age accounted for)	25.46	8.77	34	260	20
Poles (over 40 years old)	18.75	9.48	51	92	15

TABLE 4

TYPICAL LOADS FOR VARIOUS LOADING CONDITIONS

(CONDUCTOR SIZE - 12.7 mm)

Loading Condition	Loading Value
Mean Wind Load	608 N/m^2
Gust Wind Load	1156 N/m^2
Mean Wind-on-Ice Load	628 N/m^2
Gust Wind-on-Ice Load	1350 N/m^2
Ice Load	25.3 N/m

TABLE 5

POLES IDENTIFIED FOR REPLACEMENT/
REINFORCEMENT FOR A 5 YEAR PERIOD

(BASED ON 11.2 KM SECTION OF THE BRITANNIA ROAD LINE)

Year No.	Action	Pole Numbers	Total
1	Replace	10, 13, 18, 29, 31, 33, 37, 39, 42, 43, 53, 56, 57, 60, 67, 69, 70, 71, 75, 76, 83, 94, 95, 96, 98, 100, 104, 110, 111, 115, 117, 121, 129, 130, 133, 142, 143, 147, 151, 163, 166, 167, 170, 171, 175, 186, 187, 189, 196, 199, 201, 203, 206, 215, 223, 229, 232, 243, 244, 255, 258, 260	62
	Reinforce	16, 30, 66, 90, 126, 141, 161, 165, 174, 176, 226, 257	12
2	Replace	--	0
	Reinforce	4, 59, 74, 80, 159, 188, 192, 233	8
3	Replace	--	0
	Reinforce	--	0
4	Replace	127	1
	Reinforce	6, 15, 207	3
5	Replace	--	0
	Reinforce	185, 224, 234	3

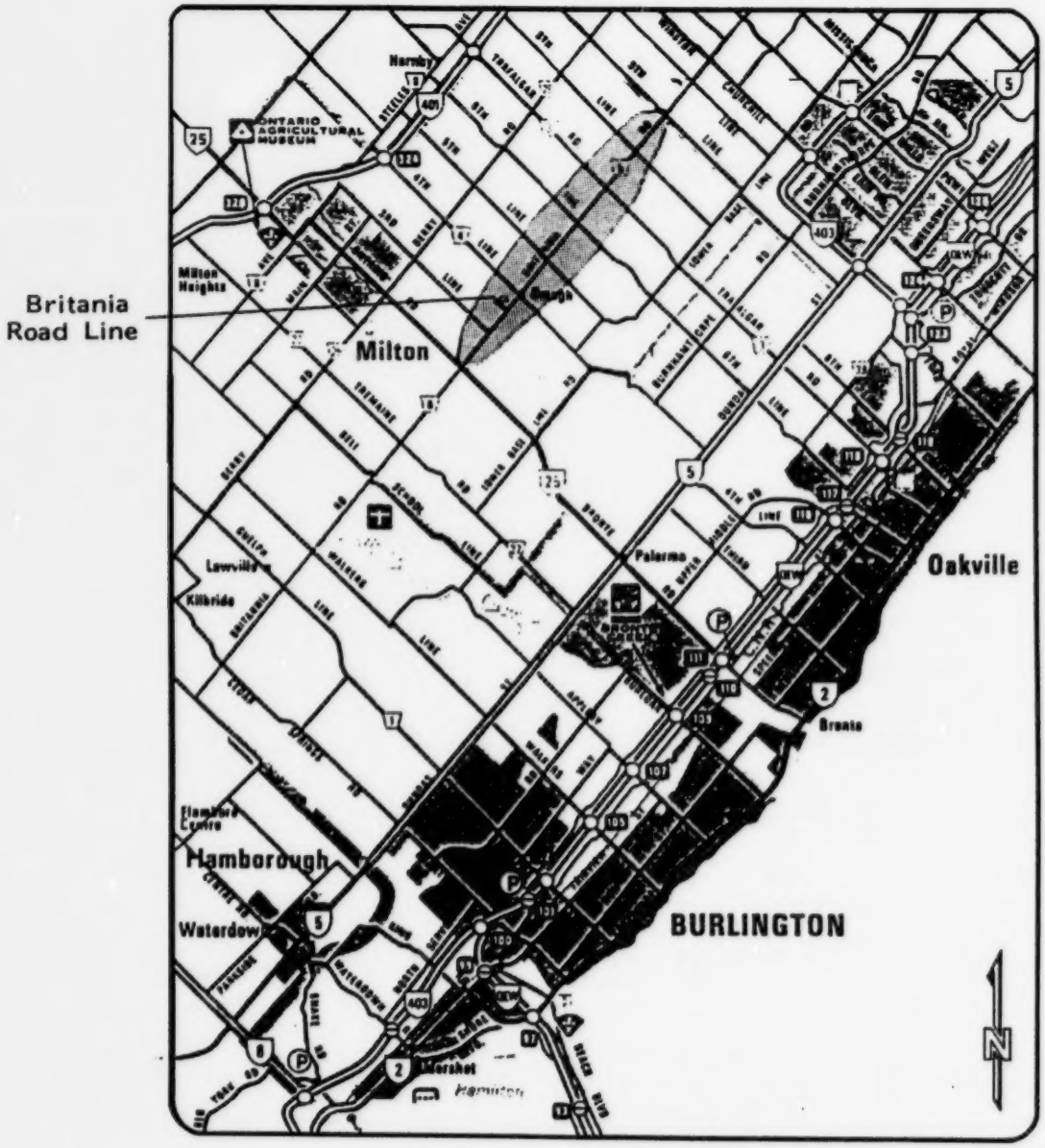

FIGURE 1
LOCATION OF THE BRITTANIA ROAD TEST LINE

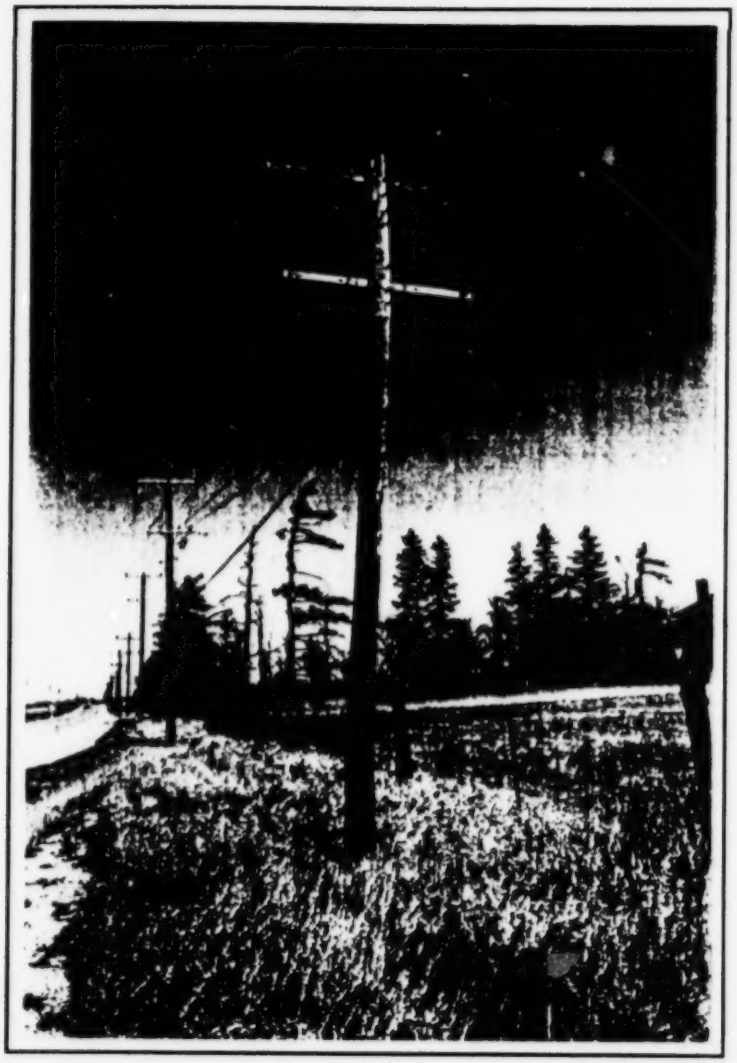

FIGURE 2

A GENERAL VIEW OF THE BRITANNIA ROAD LINE

FIGURE 3

A POLE WITH SIGNIFICANT ABOVE-GROUND LINE DECAY

FIGURE 4

A POLE WITH CONSIDERABLE STRUCTURAL DAMAGE

FIGURE 5

A POLE WITH SIGNIFICANT LOSS OF SURFACE WOOD

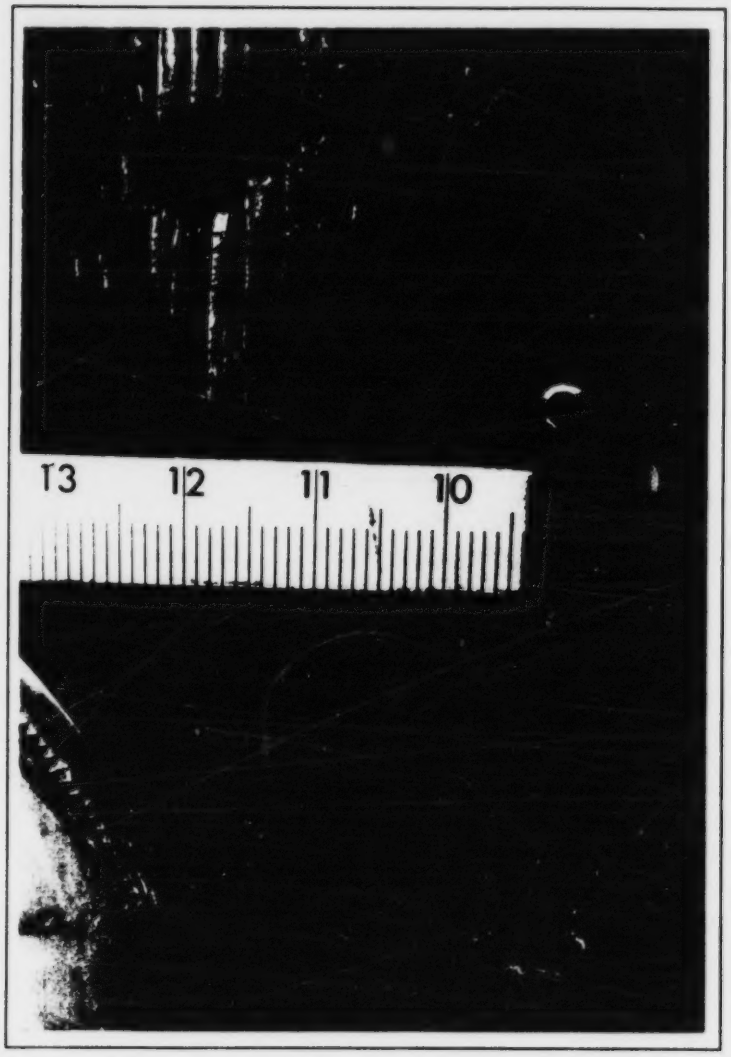

FIGURE 6

A POLE WITH A DEEP LONGITUDINAL CRACK

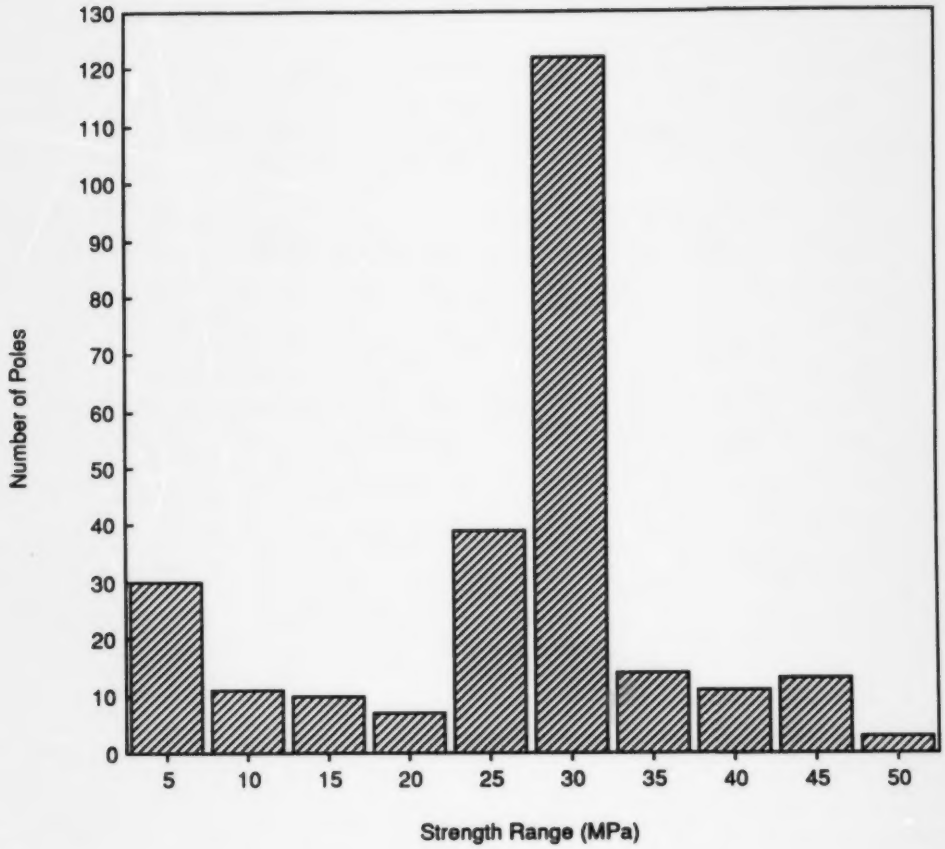

FIGURE 7

HISTOGRAM OF POLE STRENGTH BEFORE LINE UPGRADING

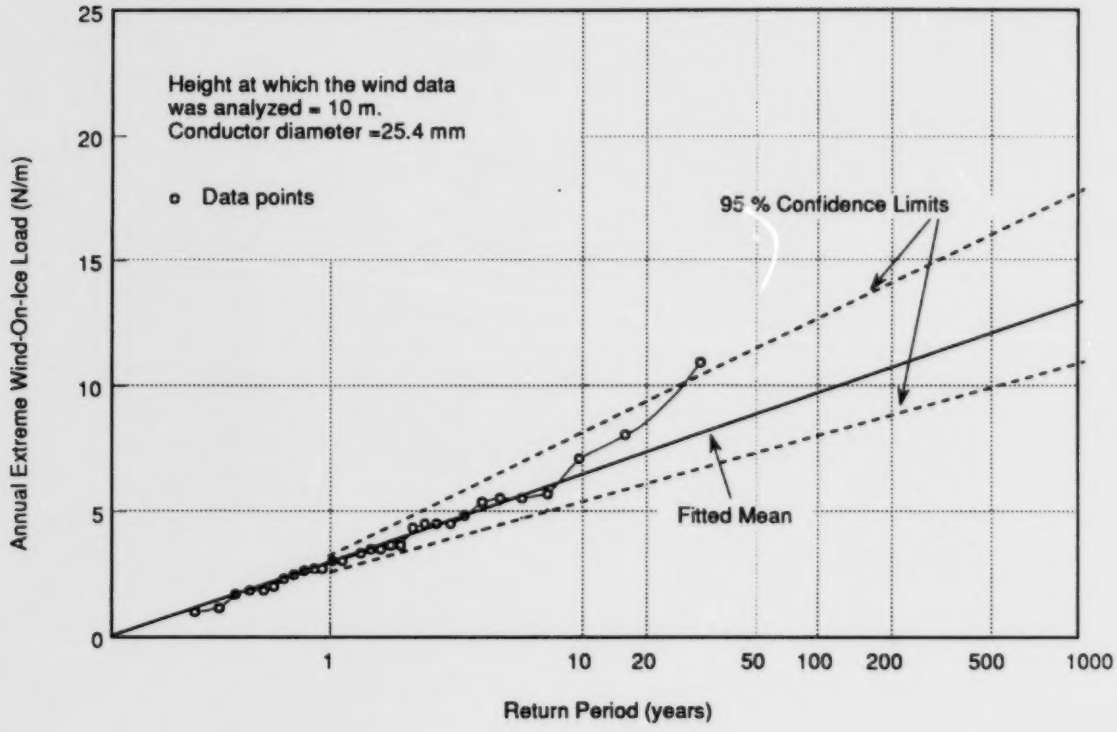

FIGURE 8

ANNUAL EXTREME WIND-ON-ICE LOAD FOR TORONTO INTERNATIONAL AIRPORT

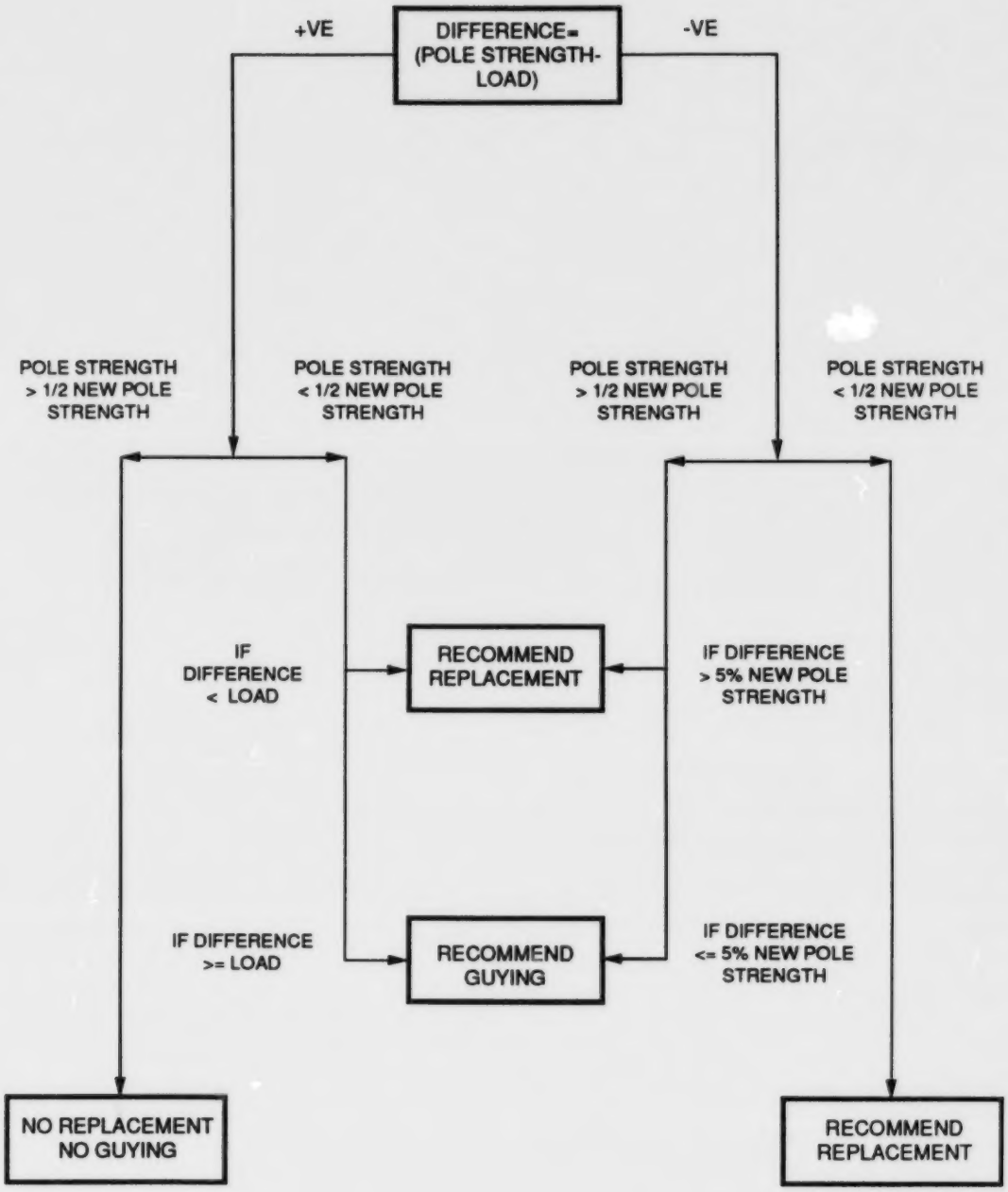

FIGURE 9

GUIDE LINES FOR POLE REPLACEMENT/GUYING

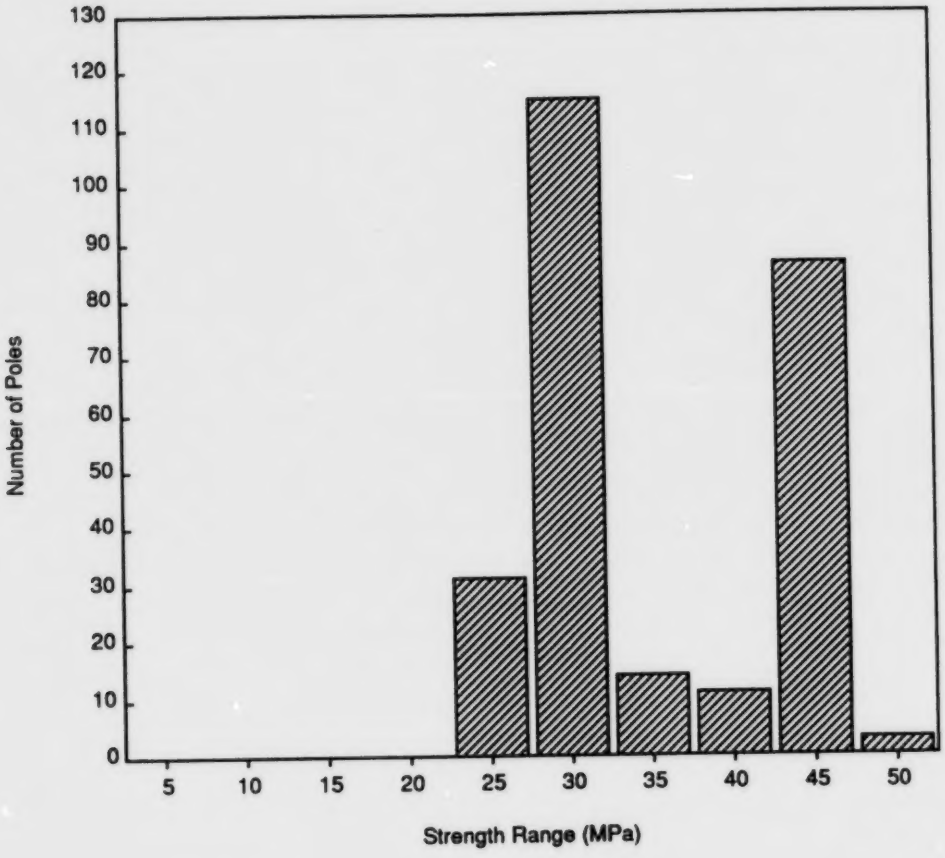

FIGURE 10

HISTOGRAM OF POLE STRENGTH AFTER LINE UPGRADING